2.25 SIGNAL INTEGRATION

In many radar systems, returns from multiple pulses are used to make a detection decision. Signal integration is the summation of several successive signal and noise pulses for the purpose of improving the detectability of target signals. Integration gain is the resulting improvement factor in the signal-to-noise ratio.

Integration may be accomplished in the radar receiver either before or after the second (amplifier) detector. Integration before the second detector is called pre-detection or coherent integration, while integration after the second detector is called post-detection or noncoherent integration. Some pre-detection integration methods are addressed in other FEs (clutter rejection in Sections 2.23 and 2.24, and pulse compression in Section 2.26). The signal integration FE described in this section includes only post-detection processing.

Many different techniques can be used to provide noncoherent integration. In simple systems, data are presented directly for display on a cathode ray tube and are visually integrated by the operator. In visual processing, the luminous persistence of the return plus the memory of the operator allow several pulse returns to be added. This physical-biological process is very complex and difficult to model. Rather than being modeled directly, it is usually approximated by using algorithms that describe hardware integrators.

In radars with hardware integrators, electronic memory and integration circuits are provided after the detection-envelope circuits. The ability of these noncoherent integrators to provide improved detectability is primarily dependent on reducing sensitivity to the stochastic nature of noise rather than on the signal characteristics. However, the integration gain depends on the target fluctuation type (Section 2.4) as well as on the radar detection-envelope type, integrator type, and settings related to probability of detection and probability of false alarm.

The intent of the Signal Integration FE in *RADGUNS* v.1.8 is to simulate the noncoherent integration performed by human operators for target detection.

2.25.1 Functional Element Design Requirements

This section discusses the design requirements for the Signal Integration FE in *RADGUNS*.

a. *RADGUNS* will have a P_d model and a threshold detection model. Signal integration is implemented only in the P_d model. The threshold detection model will not implement signal integration (see Section 2.25.2 for a comparison of the P_d and threshold detection models).

b. The Signal Integration FE will calculate the number of pulses integrated (NPI) for both land and sea terrain types.

c. The NPI will depend on the target illumination time period and the pulse repetition frequency.

2.25.2 Functional Element Design Approach

This section contains descriptions of logic and algorithms needed to implement the requirements of Section 2.25.1.

Target detection is accomplished in *RADGUNS* by simulating either a P_d model or a detection threshold model. The P_d model is based upon the Marcum-Swerling functions developed at the Johns Hopkins University Applied Physics Laboratory and later modified by L. V. Blake at the Naval Research Laboratory (NRL). The Pd is calculated from the signal-to-noise ratio (S/N), number of pulses integrated, probability of false alarm (P_{fa}), and the target fluctuation type. If the computed P_d exceeds a specified value, the target is detected. The detection threshold model simply compares the S/N ratio to a set ratio required to achieve signal detection. Signal integration is not implemented in the threshold detection model in *RADGUNS*.

In the P_d model, signal integration is intrinsically interwoven with two other FEs: Signature Fluctuations (Section 2.4) and Detection Threshold (Section 2.22). The P_d model is described in detail in Section 2.4. The portion of this model defined to be the Signal Integration FE is simply the calculation of the number of pulses to be integrated.

Design Element 25-1: Number of Pulses in a Target Return

A target will have radar pulses impinging on it from the time that the leading edge of the radar beam intersects the target until the time that the trailing edge of the beam passes the target. In other words, pulses will hit the target while the target is within the beamwidth of the radar. The slower the angular scan rate of the radar, the longer a target exists within the beam; this generally results in more pulses hitting on the target. However, a sea terrain type changes the number of returned pulses, depending on the roughness of the sea. The first two equations below apply to land, while the third equation applies to sea environments. The number of pulses, n_B, generated in a scan across the angular span of the radar beam, is determined by the following equation (Reference 3, equation 2.30):

$$n_B = \frac{\theta_B f_p}{\theta_s} = \frac{\theta_B f_p}{6\omega_m} \qquad [2.25\text{-}1]$$

where
θ_B = antenna beamwidth (deg)
f_p = pulse repetition frequency (Hz)
θ_s = antenna scan rate (deg/s)
ω_m = antenna scan rate (rpm)

The above equation is used in *RADGUNS* for radar antenna boresight elevation angles less than or equal to ten degrees while in circular search or perfect cueing mode. For circular search or perfect cueing mode with a boresight elevation angle greater than 10 deg, or while in sector search mode at any elevation angle, n_B has the following form (Reference 13, Equation 2.16):

$$n_B = \frac{\theta_B f_p}{\theta_s \, cos(\varphi_{el})} \qquad [2.25\text{-}2]$$

where
θ_B = antenna beamwidth (deg)
f_p = pulse repetition frequency (Hz)
θ_s = antenna scan rate (deg/s)
θ_{el} = antenna boresight elevation (rad)

The above equation strictly applies only if $\theta_B/cos\varphi_{el}$ is less than 360 deg; for practical application, it applies when $\theta_B/cos\varphi_{el}$ is less than 90 deg. (Reference 13, page 2.18).

Design Element 25-2: Number of Pulses Integrated (NPI)

The number of pulses in a target return may not necessarily be the number processed as a unit by the signal processing system. The algorithms for determining the NPI for *RADGUNS* v.1.8 were identified through a reverse engineering process. No independent reference was cited by the developer (nor found by the verification agent) to corroborate this design element. The descriptions which follow are based on manual code inspection.

Only one pulse is integrated for all land forms if the apparent range from the radar to the target is less than the range to the horizon. The only condition in *RADGUNS* for the NPI to be set to the number of pulses returned from the target is when the target range is greater than the range to the horizon.

A specialized NPI calculation occurs for a sea terrain type and a radar-calculated target slant range less than the range to the horizon. Under these conditions, the NPI is calculated as follows:

$$NPI = \frac{1.533 \cdot s \cdot n_B \cdot t_p}{\lambda} \qquad [2.25\text{-}3]$$

where s = sea state chosen by the user (1-8)
n_B = number of pulses returned from target
t_p = time interval between pulses (s)
λ = wavelength of acquisition radar (m)

The constant factor 1.553 is the product of 0.0167 • 0.31 • 300.

2.25.3 Functional Element Software Design

This section contains the software design necessary to implement the signal integration requirements and design approach. It is organized as follows: the first subsection describes the subroutine hierarchy and gives descriptions of the relevant subroutines; the next subsection contains logical flow charts and describes important operations represented by each block in the charts; the last subsection contains a description of all input and output data for the functional element as a whole and for each subroutine that implements signal integration.

Integration Subroutine Design

RADGUNS uses Subroutine PDET to calculate the number of pulses integrated. For the subject AAA system, PDET is called by one of two subroutines, depending on the radar search mode chosen by the user. The perfect cueing mode (Subroutine PERCUE) does not represent a real-world system; it maintains the antenna boresight pointing directly at the target. PERCUE is used when a radar search pattern is not known, or when target detection is not in question. A circular or sector search mode (Subroutine SRCH1) simulates a search of the sky until a target can be spotted on a PPI scope by an operator. Subroutine SRCH2 is similar to SRCH1, but SRCH2 models radar systems other than the subject radar. The

RADGUNS program main routine is called AAASIM. Figure 2.25-1 shows the call hierarchy associated with the Signal Integration FE. The shaded block in the call tree denotes the module that directly implements the FE. Table 2.25-1 contains a brief description of each of these subroutines.

TABLE 2.25-1. Subroutine Descriptions.

Module Name	Description
AAASIM	Main routine to simulate AAA system
PERCUE	Search for target with antenna cued to target position
SRCH1	Search for target in sector search or slow circular scan mode
SRCH2	Search for target in circular scan mode
PDET	Calculates number of pulses integrated
PRBDET	Simulates integration gain and the operator's ability to "integrate" pulses on the PPI scope with the eye-brain system
INPUT1	Initializes input parameters 1-8 from the input parameters file
INPUT2	Initializes input parameters 9-27 from the input parameters file
RDRDAT	Initializes system-specific radar parameters
Note: Modules implementing the Signal Integration Functional Element are identified in bold letters	

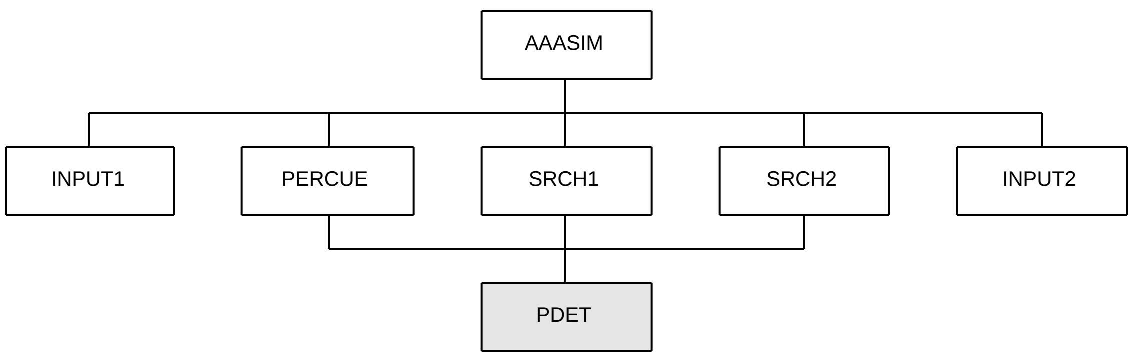

FIGURE 2.25-1. Signal Integration FE Subroutine Call Tree.

Logical Flow Diagram for Signal Integration. The Signal Integration FE is implemented by subroutine PDET. The functional flow of Subroutine PDET is shown in Figure 2.25-2. The figure contains input, output, and internal variables that will be discussed in the next section. Variable names are enclosed in parentheses. The blocks are numbered for ease of reference in the following discussion.

The range to the target as determined by the radar is PDET input argument BSRG. The radar boresight elevation angle is input argument BSEL. These inputs are utilized by PDET as described in the blocks below. Input argument SN, the S/N ratio, is utilized in Subroutine PRBDET (last oval in flow chart), which implicitly simulates integration gain and operator visual integration.

Block 1. The calculation of NPI depends on the search mode chosen by the user. If sector search was chosen, Block 2 is executed. If perfect cuing or circular search was chosen, Block 3 is executed.

Block 2. For a sector search mode, the number of pulses returned from the target is calculated based on Equation [2.25-1], and stored in variable NPULSE.

Blocks 3 through 5. If perfect cuing or circular search mode was chosen, the number of pulses returned from the target, NPULSE, is calculated in Block 5 using Equation [2.25-1] for its valid range of radar boresight elevation angles (variable BSEL, 0-10 deg). If the boresight elevation is greater than 10 deg, Equation [2.25-2] is used to calculate NPULSE.

Blocks 6 through 11. If the range of the target as calculated by the radar system is less than the range to the horizon (Block 6), and a sea terrain type was chosen by the user (Block 7), two execution branches are then available. For the applicable radar system, however, the number of pulses always is greater than zero (Block 8), so Block 9 always is executed to calculate the number of pulses integrated (variable NPI); the NPI for the sea state terrain type is calculated as defined by Equation [2.25-3]. If a sea state is not chosen (Block 7), land terrain is used, and NPI is set to one in Block 11.

If the range of the target calculated by the radar system is equal to or greater than the range to the horizon (Block 6), the remaining three blocks are applicable.

Blocks 12 through 14. The decision logic of Block 12 indicates that two execution branches are possible. For the applicable radar system, however, the number of returned pulses always is greater than zero, so Block 14 is never executed. Block 13 is executed to set the number of pulses integrated (variable NPI) to the number of pulses returned from the target (variable NPULSE).

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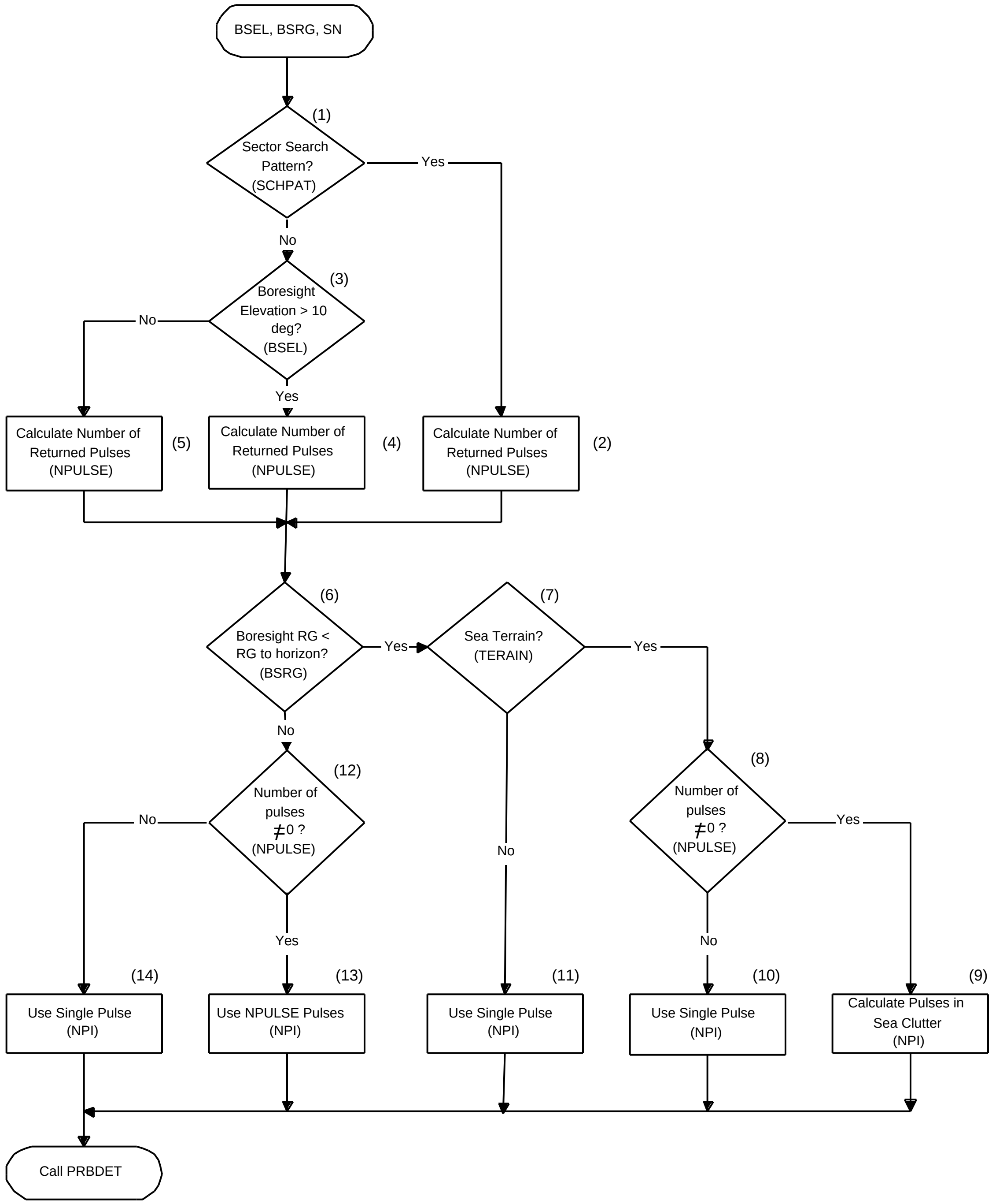

FIGURE 2.25-2. Signal Integration Flow Chart.

Variable NPI is passed to Subroutine PRBDET as an argument. The operator's ability to "integrate" pulses on the PPI scope with the eye-brain system is assumed to be implicit in the P_d model included in PRBDET. Section 2.4, Signature Fluctuations, and Section 2.22, Detection Threshold, describe the aspects of the P_d model not included in the Signal Integration FE.

Functional Element Inputs and Outputs

Table 2.25-2 defines the output of the Signal Integration FE. Table 2.25-3 lists user-defined input data which affects the operation of the FE. Table 2.25-4 describes subroutine local variables that are inputs to the FE.

TABLE 2.25-2. Functional Element Output.

Name	Description
NPI	Number of pulses integrated

TABLE 2.25-3. User Input.

Variable Name	User Options	Description
SCHPAT	PERC, CIRC, SECT	Perfect cueing, circular, or sector search mode
VHORO	Fixed number, 1-60 deg/s	Antenna scan rate; fixed and not user-selectable in sector search mode, user-selected in circular search mode
TERAIN	LAND, SEA	Terrain type
ISEAST	1 = Smooth 2 = Slight 3 = Moderate 4 = Rough 5 = Very rough 6 = High (gale) 7 = Very high 8 = Precipitous	Sea state

TABLE 2.25-4. Local Variable Inputs to FE.

Variable Name	Module	Description
NPULSE	PDET	Number of pulses in a target return
SIGMAV	PDET	Intermediate calculation of Equation [2.25-3], NPI for a sea terrain type

Subroutine PDET is the primary module which implements integration. Inputs and outputs of PDET are identified in Table 2.25-5. Variables listed in bold letters denote those which directly implement the Signal Integration FE.

TABLE 2.25-5. Subroutine PDET Inputs and Outputs.

SUBROUTINE: PDET					
Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
BSEL	Argument	Boresight elevation angle (rad)	PD	Argument	Probability of Detection
BSRG	Argument	Measured slant range to target (m)			
SN	Argument	Signal-to-noise absolute power ratio			
PRIA	Common	Transmitter pulse repetition interval (s)			
RDRSYS	Common	Radar system			
RHORIZ	Common	Range to horizon (m)			
SCHPAT	Common	Radar search pattern			
ISEAST	Common	Sea state			
TERAIN	Common	Terrain Type			
VHORO	Common	Antenna scan rate (deg/s)			
WLNTHA	Common	Transmit wavelength, acquisition (m)			

2.25.4 Assumptions and Limitations

The following statements are the assumptions and limitations associated with the modeling of signal integration in *RADGUNS*.

a. A post-detection noncoherent integration method, which is the operator's ability to "integrate" pulses on the PPI scope with the eye-brain system, is assumed to be implicit in the P_d model.

b. Integration gain is assumed to be implicit in the P_d model.